A New Framework For Quantifying Prehistoric Grave Wealth

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Abstract

Quantifying wealth in prehistoric graves is a long-standing unresolved issue. Previous approaches have focused on only one or a few aspects of grave wealth or grave good value, e.g. scarcity, or total number of object types (TOT), thus neglecting other value aspects, or, if combining value parameters, not in a reproducible or transparent way which makes application or comparison with other cases difficult. This study presents a new method of combining different aspects of grave good value such as manufacturing time and skill, case-specific scarcity, prestige, and raw material distance, as well as estimated meat consumption from animal bones, all equally weighted and, in this study, used in PCA and to calculate a Gini index. This Gini index can then be combined with Gini indices from more general grave wealth measures, including TOT and grave pit depth to form a more balanced Gini index of overall grave wealth. All of these parameters are calculated in a flexible and semi-automated framework based on experimental and prehistoric crafts reference data, which can be continuously updated and fine-tuned, flexibly integrates the respective chaînes operatoires, and which is openly available. As a case study, the framework was applied to a dataset of 81 graves with preserved skeletal remains from 46 sites of the Corded Ware Culture (CWC) in Moravia, Czech Republic. PCA analysis of the grave good measures on these data along with age and sex/gender determination shows that males are overall richer in grave goods than females, that juveniles have the highest meat expenditure, and that young adults rarely have visible meat expenditure.

Keywords: grave goods; grave wealth; Moravia; Corded Ware Culture; Gini index; prehistoric inequality

Highlights: New open framework for quantification of grave wealth combining a range of different grave good value and grave wealth aspects; Gender and age groups correlate differently with these wealth measures, showing different modes of funerary wealth expression.

1 Introduction

Wealth may be defined in different ways in a given society, and may have varying focus in different economies, regions and periods. A general framework for characterizing main wealth types based on a comparative analysis of ethnographic data has been proposed by Mulder et al. (2009) and Smith et al. (2010), summarized in Smith, Kohler and Feinman (2018). This includes embodied wealth (e.g. body weight, grip strength, practical skills, and reproductive success), relational wealth (social ties in food-sharing networks and other types of assistance), and material wealth (land, livestock, and house and household goods).

The Gini coefficient, which summarizes inequality in a population as a single number between 0 (100% equal) and 1 (100% unequal) based on income, has been a popular tool in modern populations because of its simplicity and because it can be compared across countries around the world (e.g. by United Nations accessed 2021). However, income data are not available for prehistoric populations, and thus, different proxy-measures have been utilized to calculate Gini coefficients. These include grave goods, domestic artefacts, house floor area, and storage sizes (see Smith, Kohler and Feinman 2018 for an overview of studies).

Another measure for modern populations, the Human Development Index (HDI), combines income, life expectancy, and education in order to measure human development in a way that can be compared across countries. Oka et al. (2018), inspired by the HDI, proposed a Composite Archaeological Inequality (CAI) index to combine inequality measures based on different material sources and across historical and archaeological sample populations, also with the purpose of comparing populations of different economies.

Grave good wealth is particularly difficult to quantify as perceived object value may vary considerably between populations and periods and is unknown to us from prehistoric materials. Some studies attempt quantification by grave good plurality (Hedeager 1992; Mittnik et al. 2019; Nieszery, Breinl and Endlicher 1995; Szmyt 2002), referred to as Total number of Object Types (TOT) in this study. However, this treats each object with equal value, no matter the material or count, which may skew grave wealth distributions (Nieszery, Breinl and Endlicher 1995: 205). Ethnographic (e.g. Dalton 1977; Olausson 1983: 12-14) and archaeological studies (Grossmann 2021; Nieszery, Breinl and Endlicher 1995; Todorova 2002) do mention some overlapping grave good value parameters, such as scarcity, manufacturing hours, distance to raw materials, required manufacturing skill, and exaggerated shapes, which can be quantified to some extent. However, in quantification studies, the focus has usually been on one parameter (e.g. scarcity) or, when combined in point systems, transparency for each value point is lacking (see SI: section 2) for more detail on this). This makes cross-study comparison difficult. The present study attempts to combine multiple value and wealth parameters (including TOT) in a transparent and reproducible way, and introduces a additional case-specific 'prestige' value measure derived from the median of the TOT range for each object category. As a case study, these measures are applied to grave data from the Moravian Corded Ware Culture.

The size of a grave pit may reflect status (e.g. Grossmann 2021), and this can be measured using volume, area or depth (the bottom of the grave in this study). However, both area and volume are likely affected by body size, and thus unrelated to status or wealth. Large grave goods (e.g. large pots) may also affect the grave pit area and volume while smaller items (e.g. metals) may have been more valuable. Grave depth should be less affected by body size (Bösel 2008: 51), and it is therefore used here as an additional measure of status. However erosion and varying measurement methods especially in older excavations adds some uncertainty to this measure (Kolář 2018: 82).

Table 1: Wealth parameter measures and their units used in this study.

Wealth parameter	**Measure unit**
TOT	represented number of grave good categories
manufacturing time	person-hours
skill	percentage (0.0, 0.2, 0.4, 0.6) of person-hours
import value	travel hours (with 7 km/h) to raw material
scarcity	total number of graves/number of graves with X material
prestige	median of TOT range for each grave good category
estimated meat (from MNI of animal bones)	kg + separate scarcity and prestige bonus
grave depth	cm

#Source Critical Considerations Using graves as a direct and universal measure of grave wealth is not straightforward. While there may be correlations between, e.g. metal-bearing or polished stone-bearing graves and more protein or nutrition intake from high trophic food such as meat and dairy reflected in δ^{15}N and δ^{13}C stable isotopes (Budd et al. 2020; Masclans Latorre, Bickle and Hamon 2020), a universal association between high trophic diet metal-bearing grave goods is still uncertain.

Even when taking grave goods at face value, it is uncertain whether they reflect the material wealth of the individual in life or material household wealth transmitted by next of kin at the burial, or perhaps even by the whole community in which case it may rather reflect social status and relational wealth. Thus material wealth and social status (and relational wealth) in a community are difficult to disentangle. However, use-wear studies of grave goods have shown that it may be possible to see if an object has been freshly manufactured (no or little use-wear), perhaps specifically as a grave good, or used or worn for a long time before the burial (Frînculeasa et al. 2020; Masclans Latorre, Bickle and Hamon 2020) by the individual or those adding their used belongings in the grave. The former could indicate lived material wealth, and the latter could indicate transmitted affectionate value. However, the grave goods in this study have not been studied in such detail, and social status and material wealth are therefore not distinguished in this study.

Organic remains (apart from skeletal material) such as textiles are very laborious to make and may have reflected important symbology and status, but are rarely preserved. If females expressed status or wealth more through textiles than males did, a male bias would appear in terms of gendered wealth and status. Some funerary rituals, potentially conveying considerable meaning and status, are also difficult to reconstruct, except for, the sprinkling of red ochre or funeral feasting, possibly indicated by animal bones in the graves. The latter is included here as estimated usable meat of whole animals in kg (by meat utility indices and minimal number of individuals (MNI)), including scarcity and prestige bonus (SI: section 5). Grave disturbance also adds uncertainty to the interpretation of burials (cf. Kolář 2012).

2 Case Study

With the rise of ancient genomics, it is now clear that the 3rd millennium BCE saw a major male-driven population influx from the Pontic-Caspian steppe/forest-steppe to Central and Northern Europe (Papac et al. 2021; Scorrano et al. 2021), although not on horseback (Librado et al. 2021), perhaps due to a population increase from intensified herding on the steppe in the late 4th millennium BCE (Wilkin et al. 2021). This new influx of people correlates extraordinarily well with the linguistic 'steppe-hypothesis' of Indo-European language dispersal (Anthony 2017; Anthony and Brown 2017; Anthony and Ringe 2015; Chang et al. 2015), including borrowing agricultural vocabulary from Neolithic farmers (Iversen and Kroonen 2017). Recent archaeogenomic studies have shown that Corded Ware (CWC) and Bell Beaker (BBC) societies of the 3rd millennium BCE tend to have been patrilinear, and practicing female exogamy (Mittnik et al. 2019; Papac et al. 2021; Sjögren et al. 2020), also supported by reconstructed Indo-European kinship vocabulary (Olsen 2019; Sjögren et al. 2020). A non-random decrease in Y-haplogroup diversity from early to late CWC in Bohemia, and elsewhere, during the early 3rd millennium BCE may also reflect competition between male lineages or 'an isolated mating network with strictly exclusive social norms' (Papac et al. 2021: 6; Zeng, Aw and Feldman 2018).

The CWC has been interpreted as relatively mobile with a mixed agriculture and herding and gathering economy (Lechterbeck et al. 2013), and more focused on the individual and the core family than the preceding agricultural societies (Harrison and Heyd 2007; Kristiansen et al. 2017: 343). CWC burial rituals are associated with burials under mounds in clear gender differentiation, reflected in body position (males lying on their right side, females on their left side) and in grave goods (males with battle-axes, females with ornaments) (Iversen 2015: 135, 166; Wiermann 2002). However, exceptions to this pattern occur (Furholt 2014), and males generally show more supra-regional patterns than females (Bourgeois and Kroon 2017; Olerud 2021).

Moravian CWC radiocarbon dates, while still relatively few in number, indicate a later occupation around 2600-2000 cal BCE than in other areas of Europe, thus overlapping with the Moravian BBC (2500-2000 cal BCE) and Proto-Unětice cultures (c. 2450-1900/1700 cal BCE) (Kolář 2018: 43-44). Due to the lack of large cemeteries and available radiocarbon dates, the data in this study is spread over several hundred years and several different sites, and therefore do not represent one coherent community, which limits the power of conclusions made here.

Moravian CWC residential areas are absent (and generally rare across the CWC) (Kolář 2018: 142), and thus this analysis focuses on graves. Unlike northwestern CWC, Moravian (and other Central European) CWC graves have metals (at least 13%, Kolář 2018: Table 13). However, less than 0.1% of CWC graves are interpreted as metallurgist graves (by metal-working tools), while Bell Beaker metallurgist graves are less than 1% (Peška 2016: 2-4). The Morava river likely kept the CWC community connected with metal producers around the Upper Danube, the Carpathian Basin, the Balkans, and possibly the steppe (Kolář 2018: 189). Moravian CWC metals have not been provenanced by lead isotope studies, but may have come from the Špania Dolina copper mine in Central Slovakia (about 200 km) and perhaps the Northeastern Alpine foothills (Kolář 2018: 170). Gold may have come from the Aries river in the Apuseni Mountains in Romania (about 700 km away, only one gold hair-decoration in this study, grave 155.1.4) where roughly contemporary alluvial gold sources have been identified (Cristea-Stan and Constantinescu 2016). Many burial mounds in

Moravia were poorly excavated and documented before World War II or destroyed by modern agriculture (Kolář 2018: 58, 79, 90) which makes it difficult to use mound size (or the presence or absence of mounds) as a wealth-proxy.

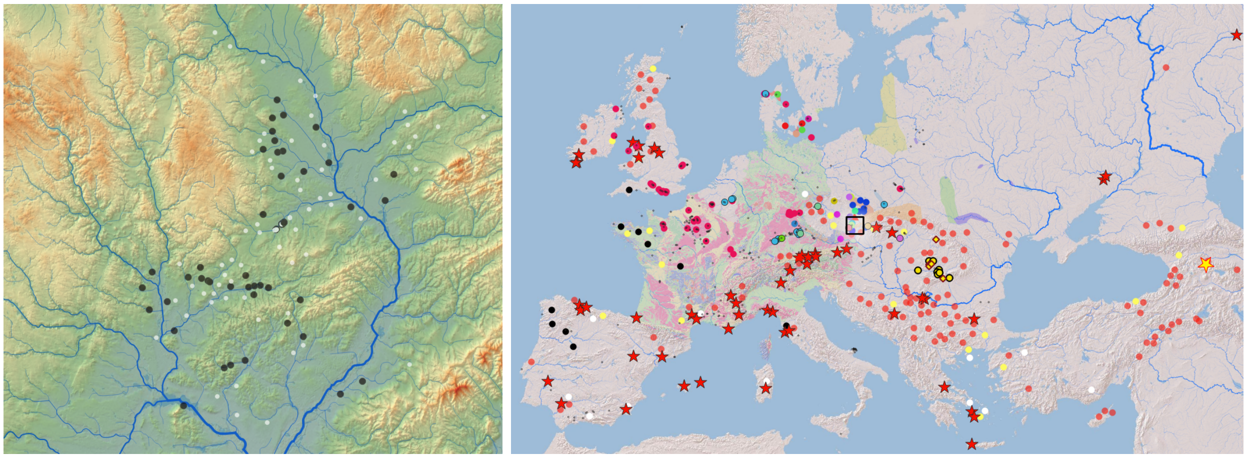

Figure 1: Left: Map of CWC sites in the study region from Sebela 1999 and Kolar et al. 2011. Sites with skeletal remains (black) and sites without skeletal remains, not included in the analysis (white). Right: raw material source data (see larger map with literature and legend in the SI) with the study area marked (black square). Collected and mapped in QGIS by the author.

2.1 Materials and Methods

Grave and grave good data for 82 Moravian individuals in 81 graves from 46 sites, mostly from ploughed-away single barrows, barrow groups, or small cemeteries were collected from the catalogues by Kolář (2011) and Šebela and Rakovský (1999). Most of them are not absolutely dated but most of them concentrate in the later Corded Ware period (phase III). Only single graves with preserved skeletal materials were used (except for one double grave, Iv4_807A/B, where the grave goods were listed separately, Kolář 2011), so that grave goods could be connected to the individual with reasonable likelihood, and so that age and sex/gender determinations could be used as qualitative variables (see Figure 1). From 69 individuals with both age and sex/gender determination, there is no significant difference in sex between the four age groups (infans 0-9, juvenis 10-19, adultus 20-39, maturus 40+) (χ^2 $p = 0.462$), but there is a significant difference when comparing age groups (79 age-determined individuals) in general (χ^2 $p =$ 4e-04), adults being most numerous and juveniles least numerous, Figure 2. Grave disturbance cannot be ruled out for some of these graves and remains a caveat, see SI: 6.1 for more details, and SI: Table 6.1 for raw grave data. Objects in the infill occurred in 8 graves adding some uncertainty to the data. However, the differences between including and excluding grave fill objects were minute for both PCA and grave good Gini indices, see SI: 6.2.

All analyses were done in R version 4.1.2 (2021-11-01) (R Core Team 2021) via RStudio (RStudio Team 2020), with the tidyverse package (Wickham et al. 2019) for data manipulation. Graphics were produced using the ggplot2 package (Wickham 2016), the Lorenz curve ggplot add-on (Chen and Cortina 2020), PCA with FactoMineR (Lê, Josse and Husson 2008) for which missing grave depth values were imputed with the missMDA package (Josse and Husson 2016), see colophon in Appendix for a list of all packages used. Gini indices were calculated using the DescTools package (Andri et mult. al. 2021), with confidence interval settings set to accelerated bias-corrected (‘bca’), 4000 bootstrap replicates, and 80% confidence level following Oka et al. (2018).

In order to calculate grave good value, five different value parameters were defined: manufacturing time (in person-hours (PH), see SI: section 4 for details), prestige/symbolic value (median of TOT range for each grave good category), scarcity (total number of graves / graves with that material as in Grossmann (2021), using the overall Moravian CWC numbers from Kolar (2018: Table 13), SI: 3.3), travel hours for imported

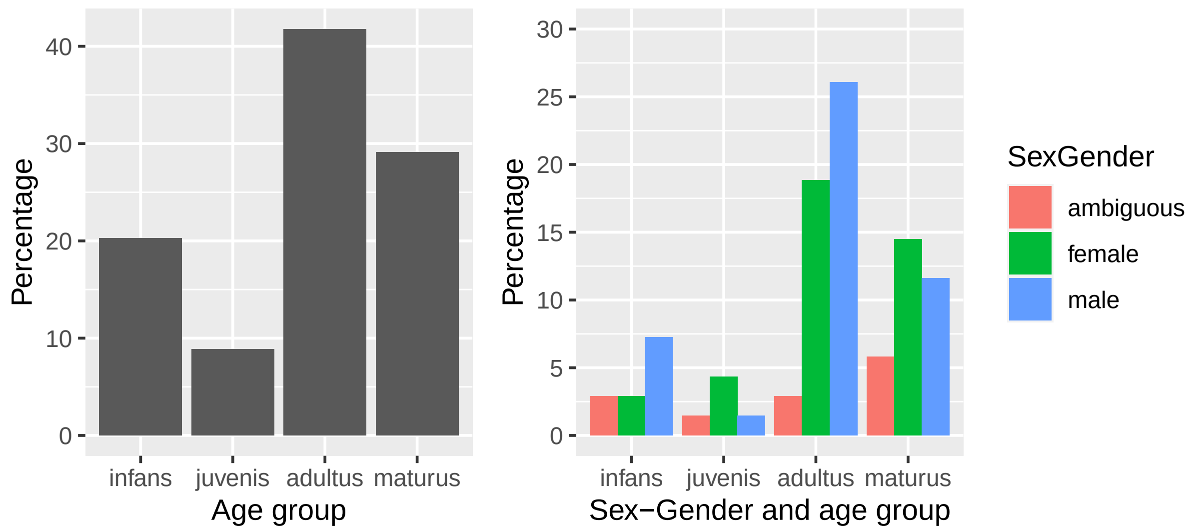

Figure 2: Percentage distribution of age groups (79 individuals, left), and sex or gender determination within each age group (69 individuals, right).

objects (assuming an average speed of 7 km/h, SI: 3.2), and a separate measure of skill bonus as percentage of PH in four different levels (low=0.0, medium=0.4, high=2.0, very high=5.0, and a hypothetical expert=10.0, for exceptional artefacts requiring >10 years of focused training to make), SI: 3.1. Estimated consumption of animal meat at the burial, which may reflect feasting (Hayden 2009), was calculated from the MNI of animal bones (assuming bones represent whole animals slaughtered), including scarcity bonus of animal bones and prestige bonus (SI: section 5).

All these measures may reflect some aspect of grave good value, and were therefore normalized to give them equal weight, and the sum of all six (incl. animal meat) for each grave was used as a measure of *overall grave good value*. Three different Gini coefficients were computed on the grave data which were used as basis for the CAI: combined grave good value, TOT, and grave depth (unimputed), see Figure 10.

The value of time in prehistory is uncertain, but food production in the Neolithic may have occupied at least 5 hours per day throughout the year, and available artefact manufacturing time may have been somewhat limited by daylight hours (Kerig 2007, see also SI: 1.1), except perhaps for very simple repetitive work such as making numerous shell beads (SI: 4.6). Thus, manufacturing time may have had some limited value. Even so, making accurate and general estimates of manufacturing time of prehistoric artefacts is extremely difficult because a myriad of factors affect the end result and the time used, not least the speed and methods of the person doing the work and how it is documented (for a more detailed discussion on this 'it depends'-dilemma, see Petty (2019)). Therefore, any time estimates used in this study are crude approximations at best and would ideally have been done through several years of data collection and controlled experiments which would be beyond the scope of this study (see SI: section 1). However, the transparency of this framework takes the initial steps towards continuous collection and improvement of such data. Since manufacturing time accounts for just 1/5 (2/5 incl. skill) of the overall grave good value, and 1/8 (2/8 incl. skill) of all grave wealth measures, inaccuracies should not affect the overall results significantly.

In order to set up a relatively flexible computation system for grave goods, the data were, inspired by the table structure in Kolář (2011), divided into the main materials: ceramics (SI: 4.1), flint (SI: 4.2), groundstone (SI: 4.3), metals (SI: 4.4), osseous artefacts (SI: 4.5), shell ornaments (SI: 4.6), and animal bones (SI: 5). This was done for both the archaeological data and for the reference data from experimental, ethnographic and prehistoric crafts people sources. The manufacturing time estimates from the reference data thus form the basis of the time estimates for the archaeological data based on a number of parameters within the *chaîne* *operatoire* of each artefact. As an example for pottery vessels (based on an interview with the historical potter Inger Heebøl at Lejre Land of Legends), size is a major (and easily quantifiable) criterion of shaping time and skill. The largest single measure of the pot's dimension gave the best correlation with time, even for different potters (SI: 4.1.1), and requires the least from the archaeological data quality. Percentage surface cover of impressed decoration, plastic decoration, polish, smoothing/beating, type and amount of temper, slip/paint (where relevant), and firing were also used as separate factors on the time estimate, usually together with size, see SI: 4.1 for details.

Flint and stone axes/adzes were divided into extraction, blank-knapping, preform-knapping (related to length), grinding (related to estimated ground surface area), sharpening, and hafting (presuming these were hafted). Skill bonus on mining, knapping, and grinding time was added for axes/adzes longer than 30 cm (not relevant for Moravian CWC), thickness below 2 cm, and extraordinary polish or shine inspired by Olausson (1983): 12-13 (see SI: 4.2).

Time for groundstone tools was initially calculated based on Mohs hardness and fracture toughness, primarily from Pétrequin (2012) on Neolithic Alpine axes. However, when later adding experimental data for battle axes and thin-butted groundstone axes from Olausson (1983), there was no correlation with these factors at all (many different combinations were tested), and Olausson (*ibid.*) demonstrates that stone tools can be made much faster than usually estimated. Therefore, the time medians were used for Alpine axes vs. other groundstone axes (e.g. battle axes) respectively, but including hardness and toughness as minor factors (SI: 4.3). This underlines that the experimental study design, methods, and documentation are critical caveats for reported manufacturing times. More systematic experimental data, beyond the scope of this study, may correlate better with hardness and toughness.

CWC metals were usually simple copper ornaments and tools shaped from wire or sheet (Kolář 2018), and in the 3rd millennium most copper ornaments generally seem to have been shaped by cold-forging (e.g. hammering and rolling) with frequent annealing in-between (Fregni 2014: 130). The whole *chaîne operatoire* was divided, following Brinkmann (2019), into mining, ore beneficiation, smelting, forging from raw nugget state (but mould manufacture, melting, and casting for cast objects), production/maintenance of metallurgical tools, and post-processing such as grinding, polishing, and, for cast metals, also removing excess metal ('jet') (SI: 4.4).

The system thus takes the detailed description of the archaeological artefacts for each material into account using separate material-specific data tables and scripts which flow into a final script adding all of the PH calculations into one final table (see SI: 6, and total result in Appendix Table 5). A simplified graph of the whole manufacturing structure is given in Figure 3.

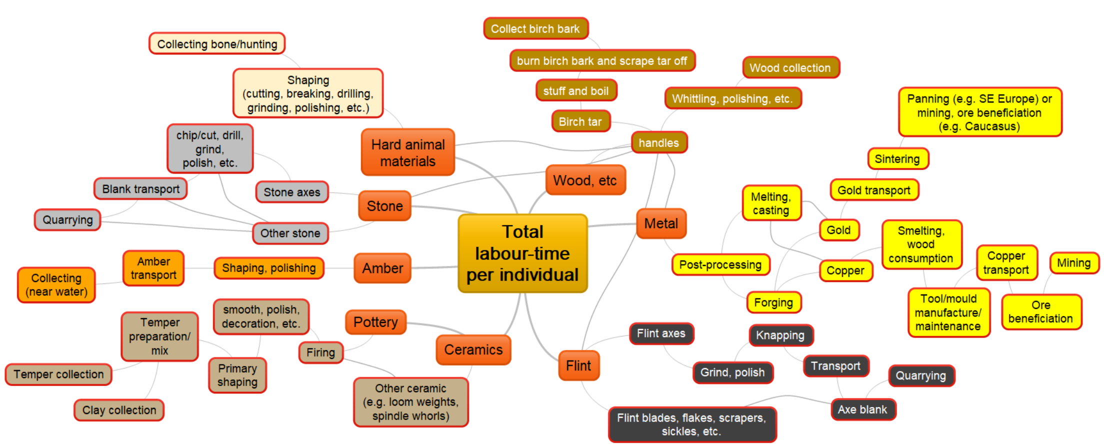

Figure 3: Simplified graph of automated PH system. Each material around the center represents one or several R scripts calculating PH depending on their respective chaînes operatoires. Drawn in MindMaple by the author.

Because Corded Ware body position in burials (females lying on their left side, males on their right side) is highly correlated with biological sex (biological or genetic), but DNA is lacking for this material and skeletal remains are not always in a state that allows morphological sex determination, a combined sex/gender variable was created in which if either morphological sex or body position (or both) is present it is used put in the sex/gender variable. However, if either of them do not align, the sex/gender determination is *ambiguous*. In this way, we get individuals enough to use in the analyses, and only three individuals are not determined at all, while still allowing for a non-binary category. There is of course still some uncertainty when only either morphological sex or gender from body position is present, which should be kept in mind when interpreting the results. Age groups were simplified from 8 (infans I-senilis) down to four (infans, juvenis, adultus, maturus), to still get meaningful results from the relatively limited sample size of 82 individuals, and to use adult individuals that with wider ranges than 10 years.

2.2 Analyses and Results

Different grave good value aspects: manufacturing time and skill, were calculated for the 82 individuals based on the reference data from experimental, ethnographic and craft people sources. The calculated results for each material were merged, see Table 5. Distance to raw material and frequency of each material within the study area were added to the material-specific tables and used to calculate import travel hours and scarcity.

Separately, the TOT measure (presence/absence for each grave good category, in this case spanning 0-10 represented categories from 'poorest' to 'richest', was calculated and used as basis for a separate Gini index, and for the prestige measure. Figure 4 shows a boxplot of the different TOT ranges for each grave good category including the median. This indicates that some categories are exclusive to the upper half of the spectrum (score in parentheses): gold hair decoration (10), shell (7.5) and tooth beads (6.5), stone axes (6), copper awls/needles (6.5), and copper knives/razors (5). Ceramic pots span the whole TOT spectrum but cluster in the lower half (3 and 4, probably reflecting the general population's TOT distribution). Battle-axes surprisingly cluster below the middle of the spectrum (4) and the single spindle whorl is positioned at the lower end (3). While some shell and tooth beads were locally available, the fact that they are exclusive to the upper TOT spectrum, is also supported by a wider study of CWC ornaments (Kyselý, Dobeš and Svoboda 2019). Thus, the 'prestige' measure allows for the exclusivity of some grave goods to behave differently from scarcity.

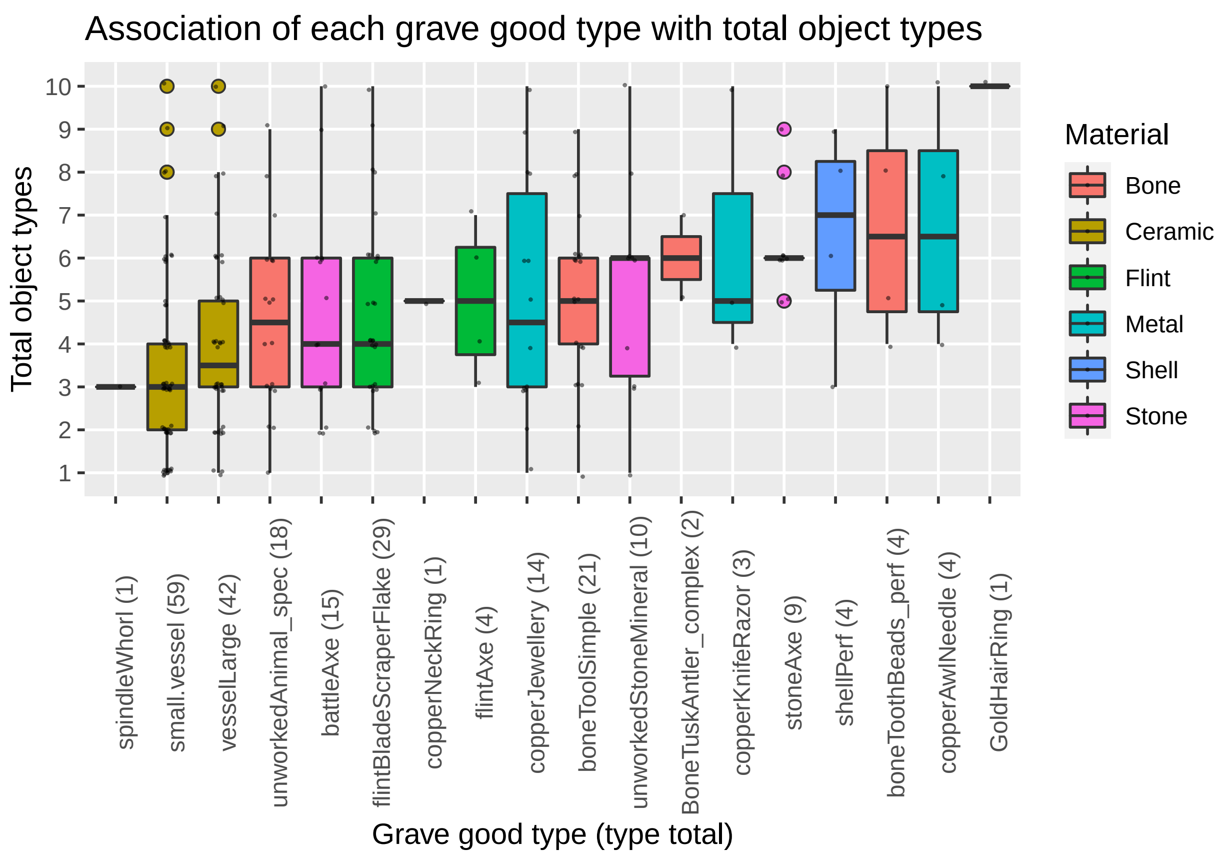

Figure 4: Association of each grave good type with TOT.

The medians mentioned above were applied as 'prestige' values instead of the raw grave good counts, then summed for each grave, and added to the other grave good value parameters in one final grave good table (Table 5).

Approximate meat expenditure from meat utility indices were calculated on cattle, red deer, horse, dog/wolf, pig, sheep/goat, and small-medium amphibians (toad and turtle), and correlated with age groups and sex/gender. There was no relation between species and age (χ^2 $p=$ 0.747) or sex/gender (χ^2 $p=$ 0.65) of the deceased .

All grave good value parameters (manufacturing time, skill, import travel hours, scarcity, prestige, and meat consumption) were normalized, and the sum of these values was calculated for each grave. A Gini index was then calculated for the normalized sum. A separate Gini index was also calculated from grave depths as reported in the catalogues (excluding graves that were too damaged to determine this).

Principal components analysis of the eight grave wealth measures as active variables (with materials as passive quantitative variables) was applied to the graves (excluding the extreme outlier graves 177.1.1 and 155.1.4), with the measures (blue arrows) graded by their percentage contribution to PC1 and PC2 (Figure 5). The PCA shows that estimated meat expenditure primarily defines PC2 while all other measures define PC1.

Grave depth is weak on PC1 and PC2, but dominates PC3 (accounting only for ~10% of overall variation, Figure 6). All measures have significant ($\alpha=$ .05) positive correlation along PC1 ($p=$ 9.43e-42 to 0.0104, but PH, TOT, prestige, skill, scarcity, and travel (in that order, $p=$ 9.43e-42 to 4.67e-16) have higher significance than grave depth ($p=$ 8.25e-07) and meat ($p=$ 0.0076).

Conversely on PC2, only meat has highly significant *positive* correlation ($p=$ 2.65e-26), less so flint ($p=$

3.35e-05, driven by two of four flint axes found in graves with high meat score), and then TOT (p= 0.0295) and prestige (0.0302) while grave depth (p= 3.169e-03), metal (p= 0.00312), travel (p= 0.00601), and skill (p= 0.0134) have significant, *negative* correlation. See, SI: Figure 7.3 for a PCA showing each species.

Two extreme outliers were removed (one from each gender, Letonice gr. 155.1.4, and Marefy gr. 177.1.1), both so elaborately furnished that they would heavily dominate the PCA space. Among many other grave goods, the male had the only gold ring in the assemblage, and the female had the most copper, as well as hundreds of dogtooth pendants and thousands of mother-of-pearl beads and remains from one *Bos sp.* individual.

Corded Ware burials are usually strictly gendered, and therefore morphological sex and archaeological gender (from the body position) are used here as one combined qualitative variable, with "ambiguous" in a few contradicting cases. A gender difference is most clear on PC1, where most females correlate negatively with males, but does not reach significance (Wilcoxon rank sum test p= 0.0857), while PC2 shows no gender relation (Wilcoxon p= 0.317).

Age group shows negative correlation for infans on PC1, but does not reach significance (p= 0.0796. Conversely, young adults (adultus, 20-39 years old) are significantly negative on PC2 (p= 0.0214), and juvenis is positive on PC2 (p= 8e-04), showing that juvenis have significantly more meat expenditure than adultus.

Interestingly, 5 of 16 (31%) infans (0-9 years old) have animal bones in their graves, while the same goes for 3 of 7 (43%) juvenis (10-19 years old), and 8 of 23 (35%) maturus (40+ years old), but only 2 of 33 (6%) adultus (20-39 years old). This shows a clear pattern that subadults and elderly have animal bones more often than young adults, see table 2. A χ^2 test of independence comparing adultus to all other age groups combined (p= 0.0063) shows that this pattern is highly significant. There is no relation between animal species and age groups (Fisher's test, p= 0.831).

Table 2: Graves with and without meat (animal bones) vs. age groups, and percentage of graves with meat.

	adultus	infans	juvenis	maturus
has_meat	2.00	5.00	3.00	8.00
no_meat	31.00	11.00	4.00	15.00
meat_percent	6.06	31.25	42.86	34.78

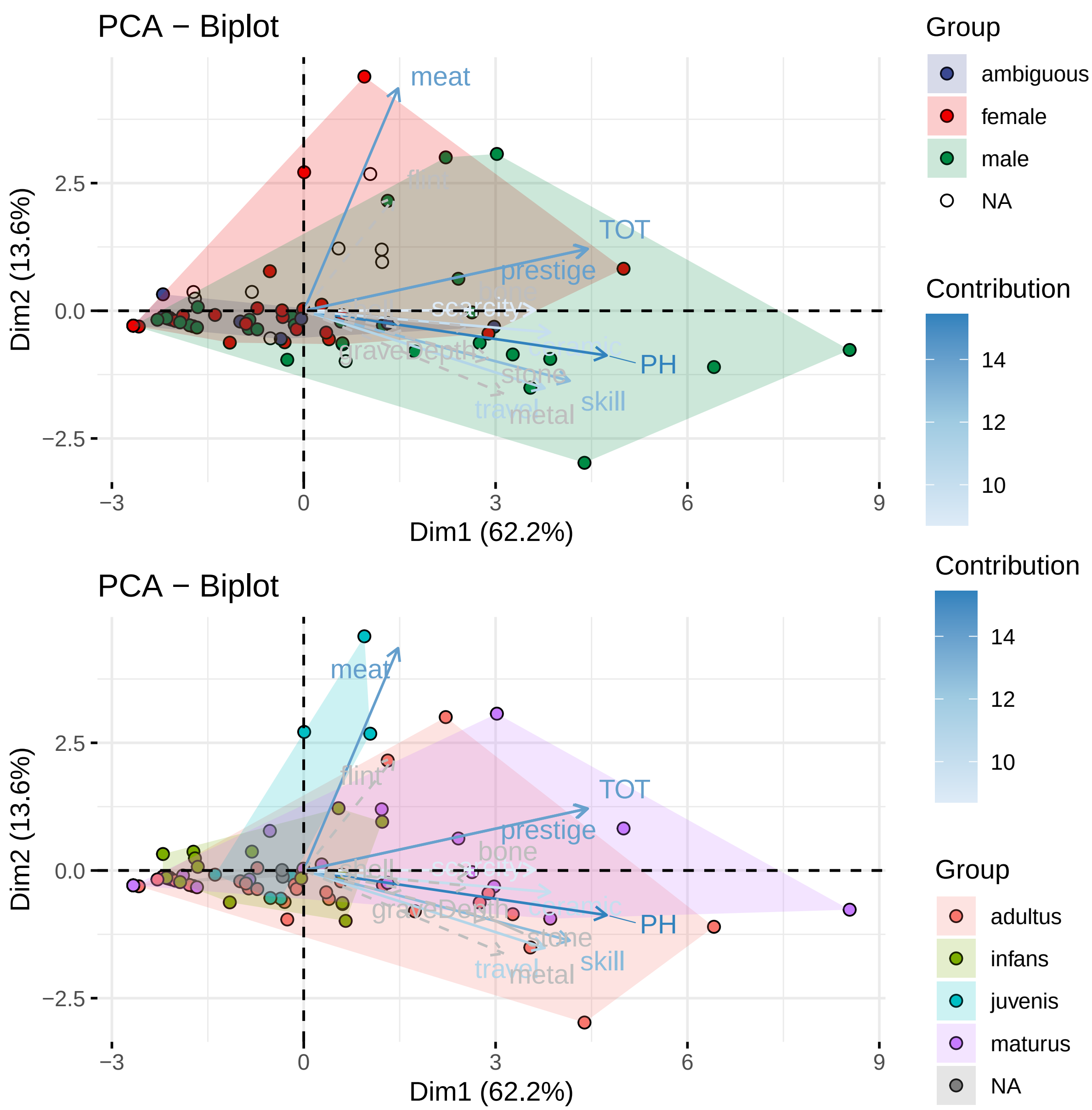

Figure 5: Biplots from a PCA of manufacturing time, skill, scarcity, travel-hours, prestige, and estimated meat consumption, as well as materials, and individuals. Group 1: low on all grave measures (along PC1), group 2: low to medium on most measures, but high on meat (along PC2), group 3 high on most measures, but mostly low on meat (along PC1).

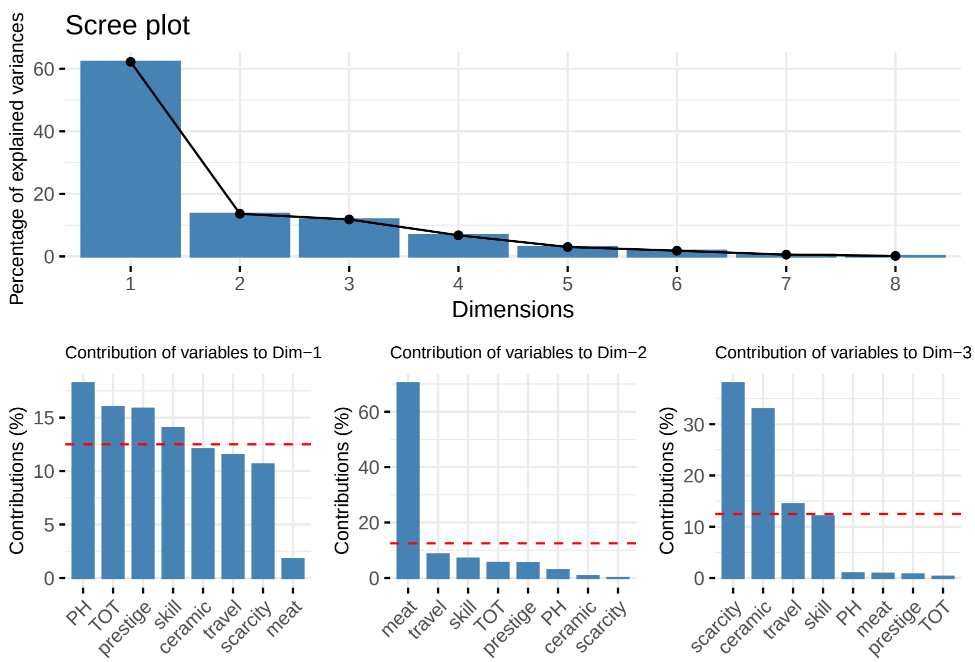

Figure 6: Top: Scree plot showing contribution of all PCs, bottom left, middle and right: scree plots of PCs 1, 2, and 3 respectively.

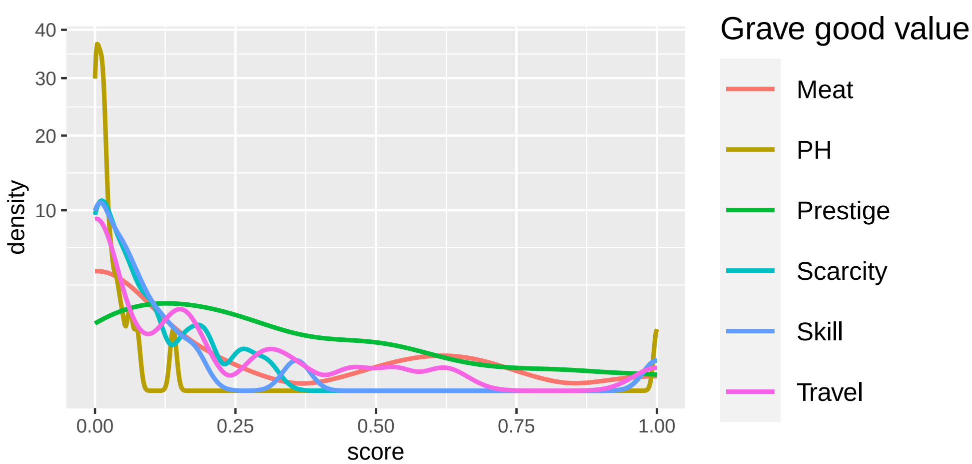

Figure 7: Square root of densities of manufacturing time, skill, scarcity, travel-hours, prestige, and estimated meat consumption

The TOT range is generally quite low (0-10, integer) compared to the other measures. This makes its resulting Gini more unstable (even more so for lower ranges such as the Bohemian CWC Vlineves cemetery (TOT 0-5) in 8. This makes the Gini become higher for lower ranges, which is counter-intuitive. Therefore, the TOT distributions were multiplied by their own maximum value, then incrementally adding one point to the TOT distribution for each Gini calculation. This makes the Gini drop drastically at first, but less so for each added point until reaching a set drop threshold of 5%, indicating a more stable TOT Gini. This makes the TOT Gini more comparable between cases, even for lower TOT ranges, see Figure 8, and better aligned with the Lorenz curve, Figure 9.

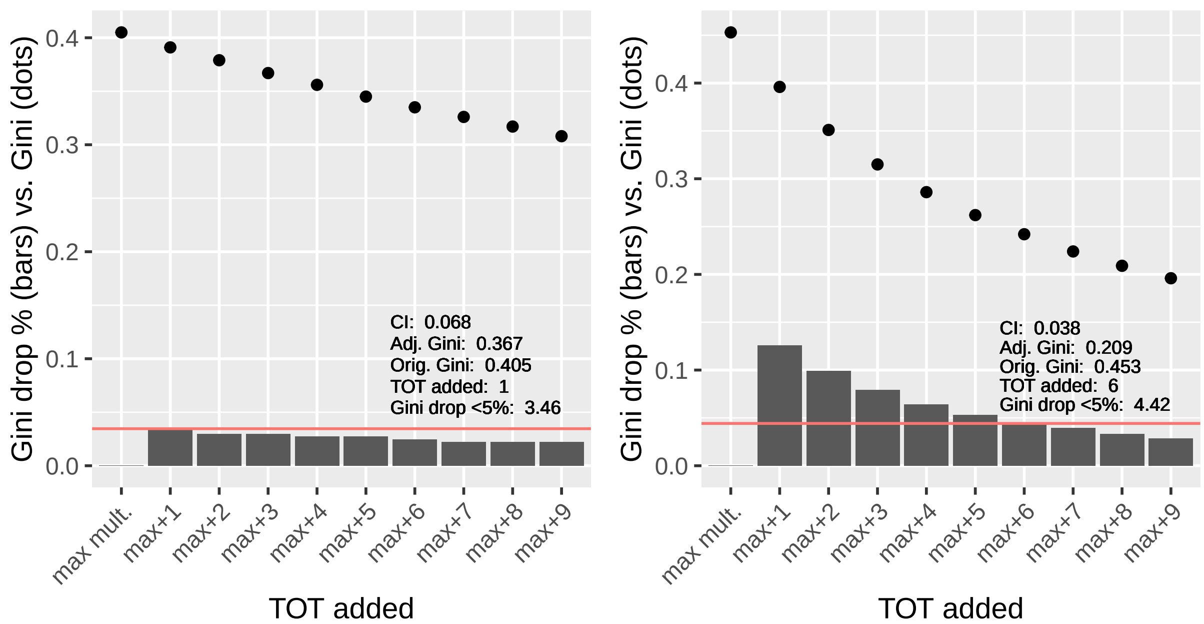

Figure 8: Comparison of drop in TOT Gini indices for every addition to the TOT distribution using the highest TOT value as starting point, applied to Moravia (left, TOT 0-10) and Vlineves (right, TOT 0-5). The drops in Gini with the least added TOT is set at a threshold of 5 percent.

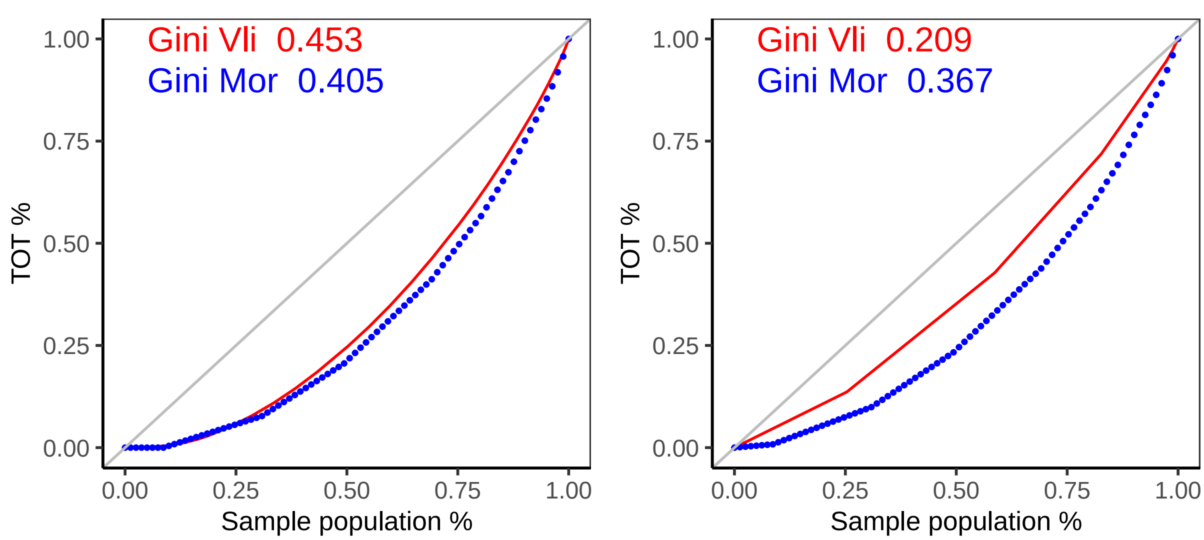

Figure 9: Lorenz curves and Gini indices for TOT without correction (left), and with correction (right) for both Vlineves (Vli, red solid curve) and Moravia (Mor, blue dotted curve).

The Gini indices are based on the data summarized in Figures 5 and 7 and Table 3.

Combining all aspects of grave wealth gives three different measures: TOT, grave depth, and combined grave good value (including meat consumption).

Table 3: Summaries of the data foundation of the Gini coefficients.

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
Total Object Types	0	1.00	3.00	2.88	4.00	10.00
Person-hours	0	4.67	18.39	46.82	29.88	1713.82
Scarcity	0	1.10	4.92	10.80	11.39	164.35
Skill bonus	0	1.62	15.93	28.69	33.06	508.73
Travel hours	0	0.00	0.00	14.26	20.18	186.43
Prestige	0	3.50	8.75	11.68	16.25	48.00
Animal meat	0	0.00	0.00	31.23	0.00	397.32
Grave good normalized sum (0-6)	0	0.12	0.31	0.55	0.78	4.06
Grave depth	2	27.50	55.00	61.44	78.25	250.00

The Gini coefficients and Lorenz curves for the 82 Moravian CWC individuals in this dataset are given in Table 4 and Figure 10 along with scarcity for comparison with Grossmann (2021). The Lorenz curve plots the percentage distribution of the sample population on the x-axis and the accumulated percentage of the given wealth measure on the y-axis ordered from the poorest to the richest graves. Grossmann (2021: 87) gets a grave good scarcity Gini index of 0.69 for Lauda-Königshofen (Southern Central German CWC 2600-2500 BCE). A scarcity Gini of 0.66 for Moravian CWC is quite close to this.

Table 4: Gini coefficients based on (adjusted) TOT, PH, and scarcity.

Gini	Lower CI	Upper CI
0.367	0.338	0.406
0.393	0.362	0.427
0.563	0.521	0.623

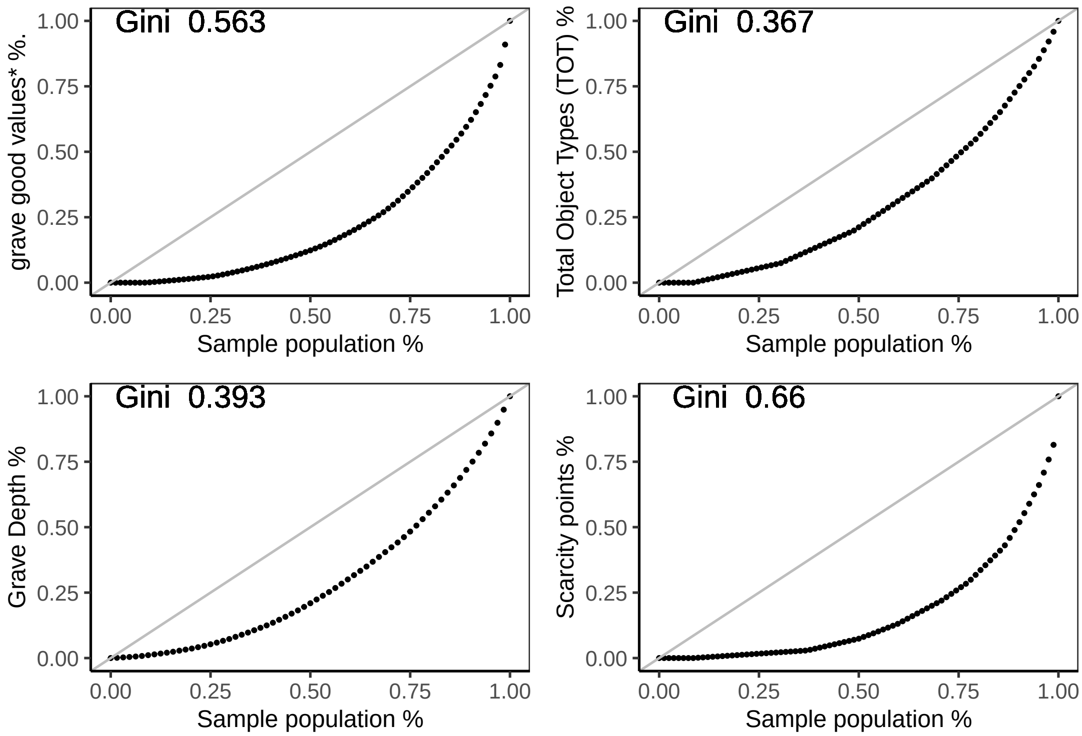

Figure 10: Lorenz curves for grave depth, Total Object Types, manufacture PH, and scarcity sensu Grossmann 2021. TOT Gini is the adjusted version. *Gini on grave good values is based on the sum of normalized values.

The grave CAI index, combining the TOT Gini, grave depth Gini, and combined grave good Gini is 0.433, which is markedly lower than when only using scarcity as in Grossmann (2021), and probably more realistic in a society not yet developed into institutionalized hierarchy as is suggested for the Bronze Age (Meller 2019: 57, 67). It is also much less than the very unequal Copper Age Durankulak community (Ginis ranging 0.61-0.77) (Windler, Thiele and Müller 2013), which uses a similar, but less transparent, point system. Fochesato et al. (2021; 2019) found that grave Ginis tend to be higher per individual than per household (i.e. hypothetical couples) across case studies, and that individual Ginis in graves should thus be corrected by a ratio of 0.91-0.92. On that background, the mean (0.915) ratio is applied in this study giving a household-adjusted grave CAI of 0.394.

3 Discussion

The meat expenditure driving PC2 in the PCA plot may indicate funerary feasting as described in Hayden (2009), food for the afterlife in case of fleshy animal parts, or, for the dog skull, perhaps a pet or a psychopomp guiding the soul of the dead (Goepfert 2012). However, interpretating animal deposits usually requires more information such as the sex, age, and general biography of each animal (Morris 2012). Similar interpretations have been made previously for a subset of this material (Kolář et al. 2012), but due to their small sample size, no relation with age could be demonstrated. Funerary feasting is also suggested for the Globular Amphora Culture (Makowiecki, Makowiecka and Osipowicz 2014; Szmyt 2006) and for the Eneolithic-Bronze Age steppe (Anthony 2007: 161, 179, 184-189, 247, 259, 325, 391, 405-409). It is curious that only 6% of adultus, the most numerous age category, had animal remains (on of them only a tooth from cattle and deer respectively), while infans, juvenis, and maturus generally had more animal remains. Nevertheless, the altogether 5 juvenis (3/7) and adultus (2/33) individuals with animal bones make up the top 5 of meat expenditure for all individuals. The individual with the highest meat score (cattle, horse, pig, and sheep/goat) was a 14-17 year-old female (osteologically), who also had one of only four flint axes in the whole dataset. No ethnographic parallel to the animal-demographic pattern of rare animal sacrifice for adultus graves was found in literature search. A hypothetical explanation could be that young adults were main providers and protectors of the family's economy. So when a young adult died, the were more dependent on the animals for survival and/or bride price or trade, while this was not the case when an individual of any other age group died, where animals could be sacrificed for the funeral (e.g. in one of the functions mentioned above).

It has been argued that grave wealth can be an exaggerated form of wealth display. Fochesato et al. (2019: 13-15 and Table S5), based on four cases with both graves and houses (Late Neolithic Balkans, and Early Dynastic Mesopotamia), find a general difference between grave good and house size Ginis of 0.244-0.343 (or an average of 28.1%) for which they downgrade the grave Gini to match the house Gini. While further studies are needed to test the general applicability of this across economies, regions, and periods, it is used in this study as a general guideline for house and grave Gini offsets.

A similar argument can be made for missing parts of the population in grave data which could have been at the lower tier of society or 'unfree'. Fochesato et al. (2019: Table S4) reconstruct the missing population in Southern Mesopotamia to be 34% and in Roman (rural?) Italy to be 9%. Both of these are state societies, and presumably much more dependent on institutionalized 'unfree' labour than expected for Neolithic societies. If we accept the association of Indo-European language with 'steppe' ancestry dispersal, we may also get an indication of the state of institutionalized 'unfree' labour in steppe-derived populations such as the CWC by looking at reconstructed 'Core-Indo-European' (Proto-Indo-European excluding the Anatolian branch) vocabulary of slavery. While such vocabulary is widespread in the daughter languages, and while military, conquering activities, and looting vocabulary is easier to reconstruct, it seems difficult to reconstruct a word specifically meaning 'slave' or 'servant' (Campanile 1998: 16-17; Anonymized 2017: 84-89). Therefore, we might not expect a large proportion of missing 'unfree' in Eneolithic steppe-derived cultures, probably less than 9% (Roman Italy), and the impact of 'unfree' on the Gini index may be limited. However, it is still theoretically possible that lower levels of society were rarely buried in a way that leaves less traces today. The large and relatively poor CWC cemetery (75 CWC flat graves, (Dobeš, Limburský and Archeologický ústav (Akademie věd České republiky) 2013)) at Vlineves in Bohemia may be a candidate for this lower level (Vlineves will be treated further in another study). Completely missing individuals may also be due to taboo, 'sky' burials, shallow graves destroyed by the plough or children's bones disintegrating faster (Kolář 2018: 68, 101). Due to this uncertainty, the author here follows Fochesato et al. (2021: 3) in not correcting for a missing population, because the data has graves without grave goods.

4 Conclusion

This study suggests combining different measures of grave wealth and grave good value. These measures are more data-driven, transparent, and include several aspects that seem to define wealth in ethnographic studies (e.g. Bösel 2008; Dalton 1977; Olausson 1983). The system's open data, flexibility, and transparency makes it more applicable and comparable between different cases, and makes it easier to expand to more grave good types, and refine with more reference data making it more robust in the future.

Importantly, applying the different measures to PCA combined with material groups, and demographic variables in the PCA shows that males generally have more elaborate grave goods than females, including in the form of long-distance connections (e.g. imported metal). At the same time deposited animal bones, potentially reflecting funerary feasting, are very rare in graves of specifically young adults, but more common for other age groups, of both sexes/genders, especially juveniles. Whether this pattern is present in other regions of the CWC will need further study from other regions and periods. No good ethnographic to this specific pattern could be found by the author at this stage. The main point of this study is that quantifying grave wealth in this way takes these questions beyond the hypothetical, and towards something that may be tested in the future with more and better data.

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Anonymized to ensure blind peer review

6 Competing Interests

The author knows of no competing interests that could have affected this study.

7 Ethics and Consent

The craft specialists mentioned in this study were used as consultants on estimated time and techniques for manufacturing prehistoric objects, and informed beforehand that their knowledge would be used in this study. For one plot (in SI: fig. 4.3) comparing the manufacturing time recorded by different potters relative to pot size, the potters have been anonymized. Any other data used was publicly available in literature or online videos.

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9 Appendix

Table 5: Calculated manufacturing time, prestige points, scarcity points, import travel points, skill points, and animal meat for feasts (estimated kg), and their respective means, and normalized sum (range of 0-6) per grave. * in site names indicates that some objects are in the grave fill of that grave. VN X in grave IDs are documentation quality rankings from Sebela 1999.

Grave ID	Site name	Manufacturing time (PH)	Prestige	Scarcity	Travel hours	Skill bonus	Meat (estimate)
100.3.1. Gr. 1	Hradisko	2.9375451	3.0	1.098404	0.0000000	1.0560000	0.00000
104.1.1.1 Grave 1 (VN 1)	Nivky	11.4866579	10.5	3.762920	0.0000000	10.5628000	0.00000
121.1.1. Gr. 1	Kloboucky	2.6835761	3.0	1.098404	0.0000000	1.5870000	0.00000
132.1.7.2 Barrow 2 (VN 1)	Kostelec u Holešova	26.4346466	11.5	49.651809	6.8571429	30.8887994	0.00000
14.1.1. Gr. 1	Blucina	23.9919286	23.0	11.386260	7.8571429	2.0695000	59.20465
143.1.3. Gr. 3	Krumvír	23.7404269	3.5	1.098404	0.0000000	42.7800000	0.00000
143.1.4. Gr. 4	Krumvír	0.0000000	0.0	0.000000	0.0000000	0.0000000	0.00000
143.1.7. Gr. 7	Krumvír	75.5643003	18.0	16.394701	57.1428571	57.1175380	0.00000
143.1.8. Gr. 8	Krumvír	0.0000000	0.0	0.000000	0.0000000	0.0000000	0.00000
148.2.1. Gr. 1	Kyjov-Netcice	32.6746369	25.0	6.410356	1.4285714	22.1426988	64.46465
155.1.1. Br. 3	Letonice	33.8304040	18.0	8.738824	0.0000000	39.7180000	0.00000
155.1.2 Barrow 4 (VN 1)	Letonice	67.4168816	23.0	8.721744	1.4285714	89.9602122	0.00000
155.1.3. Br. 5	Letonice*	28.9813672	12.5	11.386260	0.7142857	20.8029041	14.10465
155.1.4 Barrow 6 (VN 1)	Letonice	238.7162360	48.0	164.349223	186.4285714	182.3080140	0.00000
173.1.4. Gr. 4	Lutín	24.2554960	11.0	8.746552	28.5714286	22.0556680	0.00000
177.1.1 Grave 1 (VN 1)	Marefy	1713.8168755	38.0	44.307320	85.7142857	508.7316869	215.70465
177.4.5. Gr. 5	Marefy	24.6017188	10.5	3.762920	0.0000000	34.0808000	0.00000
197.1.1	Morkuvky*	61.6131055	20.5	16.386972	28.5714286	41.7370920	0.00000
198.1.1. Gr. 1	Mostkovice	30.0583667	11.0	8.746552	28.5714286	26.0950060	0.00000
199.1.2. Gr. 2	Mouchnice	34.6897417	6.5	1.098404	0.0000000	50.2000000	0.00000
20.1.1. Gr. 1	Boleradice	12.4277388	16.5	26.707365	14.2857143	1.3003963	397.32465
207.1.1. Gr. 1	Nechvalín	11.9533223	3.0	1.098404	0.0000000	5.5939333	0.00000
207.1.3. Gr. 11	Nechvalín	35.1482103	11.0	1.098404	0.0000000	43.2576667	260.80465
207.1.6. Gr. 18	Nechvalín	12.9672313	7.0	3.762920	0.0000000	13.6943333	0.00000
232.1.1 Grave 5 (VN 1)	Pavlov	85.0965755	6.5	41.978853	115.7142857	72.6705558	0.00000
232.1.2. Gr. 14	Pavlov	27.0707074	31.0	31.683268	14.2857143	19.8789113	226.22465
24.2.1. Gr. 1	Brno	3.5614859	3.0	1.098404	0.0000000	1.7350000	0.00000
240.1.1. Br. 1	Podolí	17.4643104	12.5	8.721744	0.7142857	26.5834230	0.00000

Table 5: Calculated manufacturing time, prestige points, scarcity points, import travel points, skill points, and animal meat for feasts (estimated kg), and their respective means, and normalized sum (range of 0-6) per grave. * in site names indicates that some objects are in the grave fill of that grave. VN X in grave IDs are documentation quality rankings from Sebela 1999. *(continued)*

Grave ID	Site name	Manufacturing time (PH)	Prestige	Scarcity	Travel hours	Skill bonus	Meat (estimate)
246.1.1. Gr. 1	Prostejov	10.1824641	3.0	1.098404	0.0000000	5.3880000	0.00000
246.3.1. Gr. 1	Prostejov	18.3568064	6.5	1.098404	0.0000000	15.7120000	0.00000
25.4.2 Grave 1	Brno-Chrlice	2.8179082	3.5	1.098404	0.0000000	1.1093333	0.00000
257.1.1. Gr. 1	Pustimer	8.0425061	3.5	1.098404	0.0000000	10.4900000	0.00000
271.1.1. Gr. 1: Skel. 1	Sivice	29.3587965	14.5	6.410356	0.7142857	39.6491940	0.00000
273.1.1. Gr. 1	Slatinky	26.3170095	11.0	6.410356	0.7142857	33.5484748	0.00000
277.1.1. Gr. 1	Slavkov u Brna	26.2845006	15.0	3.762920	0.0000000	27.1078000	258.55865
281.1.1. Gr. 1	Smrzice	21.7578654	16.5	16.386972	28.5714286	10.8202580	0.00000
291.1.1. Gr. 1	Stráznice	20.6793605	7.0	3.745840	0.7142857	23.8743177	0.00000
294.1.1 Grave 5 (VN 1)	Sudomerice	4.4794948	3.0	1.098404	0.0000000	1.8263333	0.00000
30.1.1 Grave 9	Brno-Starý Lískovec	0.0000000	4.5	0.000000	0.0000000	0.0000000	35.14465
30.1.2 Grave 36 (VN 1)	Brno-Starý Lískovec	63.4021256	25.5	11.386260	29.2857143	86.0775235	0.00000
30.1.3 Grave 42 VN 1	Brno-Starý Lískovec	1.7454067	7.5	1.098404	0.0000000	0.6893333	24.62465
30.1.4 Grave 70 (VN I)	Brno-Starý Lískovec	2.7631375	7.5	1.098404	0.0000000	1.0926667	14.10465
312.1.1 Grave 1 (VN 1)	Tešetice	49.3192328	21.5	31.666188	22.1428571	22.3207915	0.00000
314.1.2. Gr. 2	Tovacov	24.6039562	7.5	8.746552	28.5714286	12.8059580	0.00000
321.3.1. Gr. 3	Tvarozná	12.4811575	8.5	6.074308	0.0000000	14.4900000	0.00000
321.3.2. Gr. 4	Tvarozná	0.0000000	0.0	0.000000	0.0000000	0.0000000	0.00000
347.1.1 Grave 1	Vícemilice	17.0818495	10.5	3.762920	0.0000000	18.5193333	0.00000
347.1.3. Gr. 3	Vícemilice	6.1599576	11.5	6.410356	0.7142857	1.7265000	0.00000
347.1.5 Grave 5 (VN 3b)	Vícemilice*	11.2656365	9.0	25.141253	14.2857143	0.8500000	0.00000
35.1.1 Grave 1 (VN 3a)	Bucovice	5.2606197	3.0	1.098404	0.0000000	2.7586667	0.00000
35.1.2 Grave 2 (VN 3a)	Bucovice	19.9993514	6.5	1.098404	0.0000000	30.3750000	0.00000
355.1.2. Gr. 2	Vresovice	47.2395961	26.0	11.386260	1.4285714	55.8230463	59.20465
368.1.1 Grave 1	Zelešice	47.6154203	27.5	30.560056	57.8571429	31.5825186	0.00000
56.1.1. Gr. 1	Celechovice na Hané	22.0401269	7.5	3.745840	0.7142857	39.3094748	0.00000
58.1.1. Gr. 1	Detkovice	19.9242759	26.0	16.386972	28.5714286	10.3389080	59.20465
72.1.1. Gr. 1	Drahlov	4.1096063	5.0	6.074308	0.0000000	1.2273333	0.00000

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Grave ID	Site name	Manufacturing time (PH)	Prestige	Scarcity	Travel hours	Skill bonus	Meat (estimate)
72.1.2 Grave 2 (VN 2)	Drahlov	21.4047878	8.0	6.410356	0.7142857	28.5003038	0.00000
93.1.1. Gr.2	Holubice IV	0.9273504	3.0	1.098404	0.0000000	0.3646667	0.00000
93.1.2. Gr. 26	Holubice IV	14.5863451	12.5	6.074308	0.0000000	7.0840000	59.20465
93.1.3. Gr. 36	Holubice IV	0.9323032	0.0	1.098404	0.0000000	0.3646667	0.00000
93.2.1. Gr. 1	Holubice VII	21.5902603	7.5	3.745840	0.7142857	25.9520000	0.00000
93.2.2. Gr. 2	Holubice VII	10.3828651	6.5	1.098404	0.0000000	5.0493333	0.00000
93.2.3. Gr. 3	Holubice VII	0.0000000	0.0	0.000000	0.0000000	0.0000000	0.00000
93.2.4. Gr. 4	Holubice VII	0.0000000	0.0	0.000000	0.0000000	0.0000000	0.00000
97.1.1 Grave 1 (VN 1)	Hoštice Farm*	102.5335631	33.5	26.682556	66.4285714	65.8423480	0.00000
Hos_801	Hostice 4	27.0978713	11.0	8.746552	28.5714286	24.7350420	0.00000
Hos_802	Hostice 4	41.3153300	23.5	11.386260	8.2857143	21.6228000	256.45465
Hos_838	Hostice 4	109.9286806	20.5	16.394701	57.1428571	59.1820813	226.22465
Hos_839	Hostice 4	16.0033157	11.0	1.098404	0.0000000	17.9370000	260.80465
Iv3_2_801	Ivanovice na Hane 3_2	18.4324584	15.5	8.738824	0.0000000	18.4131333	0.00000
Iv3_2_803	Ivanovice na Hane 3_2	13.7488790	7.0	3.762920	0.0000000	16.1444667	0.00000
Iv3_2_804	Ivanovice na Hane 3_2	1.0034493	3.0	1.098404	0.0000000	0.3980000	0.00000
Iv3_2_805	Ivanovice na Hane 3_2	13.6495438	4.5	8.746552	28.5714286	8.1089820	0.00000
Iv3_2_806	Ivanovice na Hane 3_2	3.3075652	7.0	3.762920	0.0000000	0.9533333	0.00000
Iv3_2_809	Ivanovice na Hane 3_2	14.8725244	14.5	13.722456	28.5714286	8.3740480	0.00000
Iv3_2_811	Ivanovice na Hane 3_2	6.8930330	3.0	1.098404	0.0000000	3.6470000	0.00000
Iv3_2_825	Ivanovice na Hane 3_2	34.1454794	14.5	18.004300	28.5714286	55.2744960	0.00000
Iv4_800	Ivanovice na Hane 4	49.1075287	21.0	16.386972	28.5714286	41.8279080	0.00000
Iv4_803	Ivanovice na Hane 4	0.0000000	0.0	0.000000	0.0000000	0.0000000	0.00000
Iv4_807A	Ivanovice na Hane 4	2.0288640	3.0	1.098404	0.0000000	1.2120000	0.00000
Iv4_807B	Ivanovice na Hane 4	1.4977915	1.0	2.647436	1.4285714	0.0000000	0.00000
Iv4_810	Ivanovice na Hane 4	127.6187313	41.5	31.658460	99.2857143	73.2873767	69.72465

9.0.1 Colophon

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